

Life Cycle and Risk Assessment of Environment-Compatible Flame Retardants (Prototypical Case Study): ENFIRO

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Introduction

Some brominated flame retardants (BFRs) have unintended negative effects on the environment and human health. Some of them show a strong bioaccumulation in aquatic and terrestrial food chains, some are very persistent, and some show serious toxicological effects such as endocrine disruption (e.g. Darnerud, 2008, Legler, 2008, van der Ven et al., 2008). During the last decade an increasing number of reports have presented evidence of these negative effects caused by BFRs. A number of BFRs (polybrominated diphenyl ethers (PBDE's), hexabromocyclododecane (HBCD) and tetrabromobisphenol-A (TBBPA) in particular) can be found in increasing concentrations in the human food chain, human tissues and breast milk (Hites et al., 2004; Schantz et al., 2003; Schecter et al 2005; She et al., 2007). Less toxic alternatives appear to be available already but comprehensive information on their possible toxicological effects are lacking. The European Commission-funded project ENFIRO investigates a prototypical case study on substitution options for specific BFRs resulting in a comprehensive dataset on viability of production and application, environmental safety, risk assessment, and a life cycle assessment.

ENFIRO approach

A practical approach (Fig. 1) is followed, in which the alternative FRs are evaluated regarding their flame retardant properties, their influence on the function of products once incorporated, and their environmental and toxicological properties. This is achieved by performing case studies, which gather a comprehensive set of information on environmental behaviour and toxicological impact, as well as an assessment of the performance of the FR in a specific application. The case studies give recommendations for industrial and governmental stakeholders.

ENFIRO starts with a prioritization and selection phase to select the most promising three FR/product combinations for further detailed studies. The three selection combinations are studied on hazard characterization, exposure and fate, FRs emissions and fire retarding properties (FR capability studies), and the technical suitability of the FRs when used as such or as mixtures in specific applications (PCBs, coatings, etc.). The collected information is analysed in a risk assessment. After collection of socio-economic information on the FR/product combinations together with the risk assessment the outcome is digested in a life-cycle assessment, including an analysis of costs and socio-economic aspects. This will finally result in a recommendation of certain FR/product combinations.

Results and Discussion

Prioritization and selection

For the selection and prioritization phase information on a range of non-brominated FRs that are viable alternatives to specific commercial BFRs through literature and other reliable scientific sources based on how they affect the material's characteristics of the polymers is collected. Information on the

performance criteria as compatibility behaviour in marketable polymers and the evaluation of fire behaviour are collected, as well as toxicological and ecotoxicological properties of the selected FRs, and the impact on function and reliability of end products, and finally economic aspects are gathered. But also information on the human and environmental exposure are collected.

Hazard characterisation

ENFIRO performs a health hazard characterisation of the selected FRs with the focus on a molecular and cellular level. The emphasis is on human/mammalian geno-, endocrine- and neurotoxicity (sensitive targets for metals, nanoclays, PFRs and BFRs) in vitro studies, including biotransformation, and a limited number of ex vivo validation studies.

The ecotoxicological hazard characterization studies investigate the acute toxicity using water and sediment toxicity tests (Daphnia, Chironomus riparius, algae PAM), and the chronic toxicity with the Daphnia and Lumbriculus variegatus tests. Bioavailability is taken into account, and structure-activity relationships for toxicity is derived.

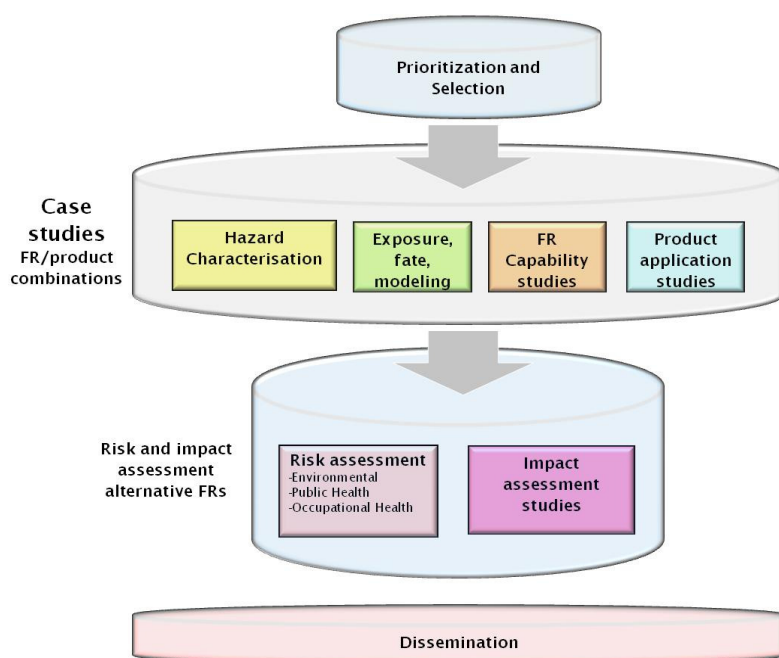


Figure 1: ENFIRO approach to study flame retardant substitution options.

Exposure assessment

ENFIRO provide a quantitative assessment of the environmental exposure that is anticipated from use of the case study flame retardants. An integrative approach centered on a structured and systematic application of modelling, experimentation and field measurements is employed.

For the modelling multimedia fate and bioaccumulation modelling tools (e.g. EUSES and

ACC-Human) are used for organic compounds, and existing biogeochemical models depending on the metal FRs to be studied, to produce an initial environmental and human exposure assessment. For nanoclays and nano-metal FRs new approaches are developed.

To assess the environmental persistence of alternative FRs, persistence testing is based on ready biodegradability testing methods. For FRs with relatively high values of K_{ow} , for which accumulation in sediments is expected to be a significant process, their biodegradation in sediments under aerobic and anaerobic condition is determined.

In the final stage a field monitoring campaign for (a number of) phosphorous based FRs and metal based FRs, and if possible, nanoclays, is conducted in several European countries to assess the environmental contamination arising from a known source (e.g. a wastewater treatment plant) as well as background contamination in a region (i.e. environmental media would be sampled at locations remote from likely sources).

FR capability

ENFIRO quantify the severity of the toxicity, smoke and heat flux of alternative FRs against BFRs in fire (smoldering and flaming) incidents. Flammability and toxicity of brominated and alternative FRs are investigated for selected prototype base polymers and FRs. The behaviour in standard tests and in large fires to study the impact on life and property safety and damage, and recyclability are examined. The severities of toxicity, smoke and heat flux of BFRs against alternative FRs in realistic fire are investigated.

Product application studies

A technical assessment of the use of alternative FRs in various applications by comparison with traditional FR systems is examined. Five FR/product applications combinations are selected:

1. Printed circuit boards
2. Electronic components
3. Injection moulded products
4. Textile coatings
5. Intumescent paint

To identify and assess the reliability risks with selected alternative flame retardants for use in printed circuit boards a physic-of-failure approach is followed. Since manufacturing processes and field conditions may contribute to the degradation of the FRs, the impact of the processes and conditions are included in the evaluations. Evaluations that likely are performed include hygroscopicity of laminates with various FRs, impact on surface insulation resistance, impact on the risk for formation of CAF, impact on the risk for delamination in laminates, impact on the integrity of via hole platings, impact on the peel adhesion of copper foils.

ENFIRO Stakeholder Forum (ESF)

An ENFIRO Stakeholder Forum with members representing FR users (large industries) was invited to guide this project. The ESF functions as a reference group for the identification, elaboration and evaluation of the drivers and barriers connected to the flame retardant substitution project. The ESF consists of representatives that exchange valuable input with the project objectives. They are requested

to give feedback to the different options and questions that are raised during the analysis of the environmental, economic and social impacts of the alternative flame retardants. The ESF consists of a balance of relevant stakeholder (groups) not only from the value chain like producers of alternatives of flame retardants, formulators and users of these substances, and waste(processing) plants but also from other institutes like NGOs and policy-related ones.

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